

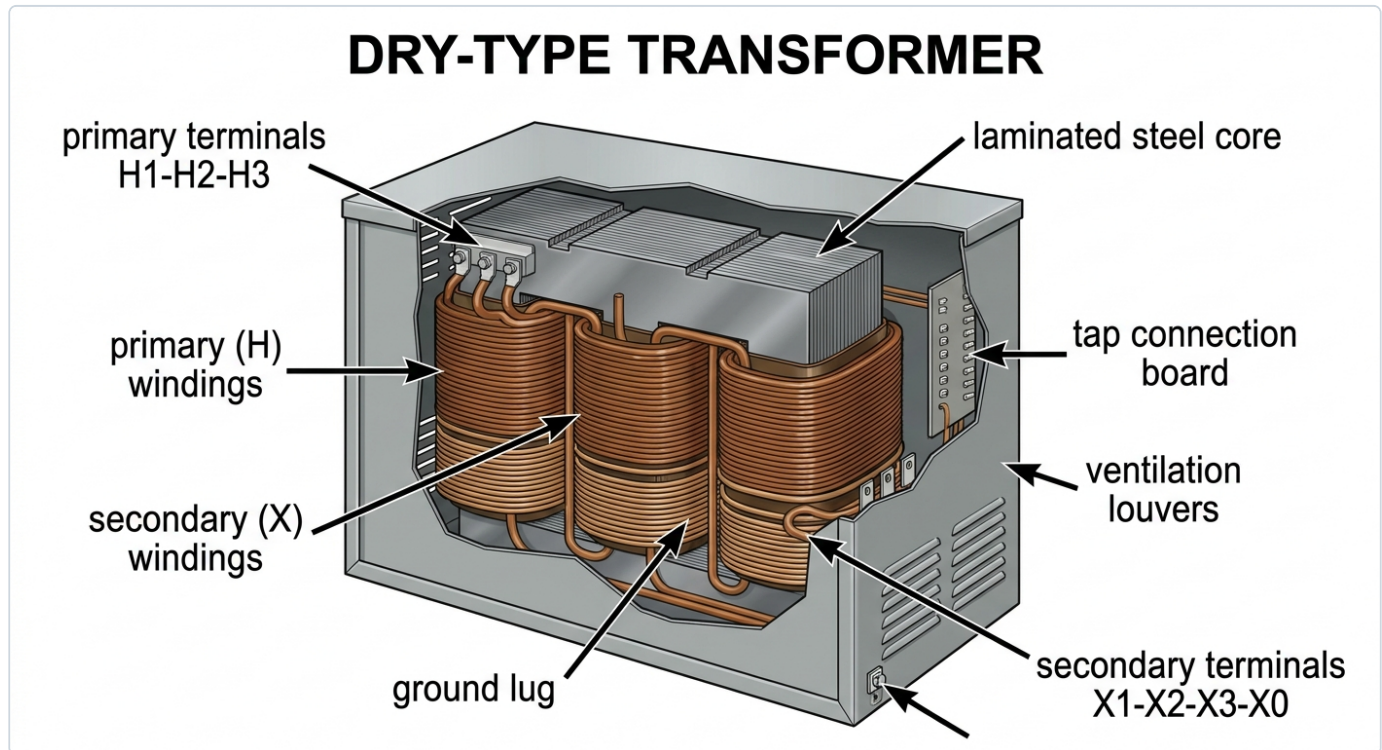
Module 1.5C — Transformer Masterclass

Voltage change made clear: construction, real nameplate numbers, %Z and fault current, vector groups, taps step by step, grounding the secondary, harmonics, protection, and install and commissioning.

Why a masterclass on this. Transformers are everywhere in a commercial building. Every time the voltage changes (480 down to 208/120, for example) there is one doing it. Understand how it is built, how it connects, how the taps work, and how to ground and protect it, and you can install and troubleshoot any of them. Get the connection or the grounding wrong and you create a hazard or a dead system. This version adds the real nameplate numbers, sizing tables for the three most common sizes, and the full install and commissioning sequence from the Schneider and Eaton instructions.

NEC 2026 renumbered Article 450. Every manufacturer document still uses the old numbers. Protection is now **450.5** (was 450.3), ventilation **450.11** (was 450.9), marking **450.13** (was 450.11), accessibility **450.15** (was 450.13), disconnect **450.16** (was 450.14), and **450.12 Grounding and Bonding** is new. 450.21 kept its number.

Part A — Inside a Dry-Type Transformer



A dry-type transformer: laminated steel core, primary (H) and secondary (X) windings, H1-H2-H3 and X1-X2-X3-X0 terminals, the tap board, ventilation, and the ground lug.

- **Core and coils** sit on neoprene vibration pads. The core is grounded to the enclosure by a visible flexible copper strap. A wye secondary brings its neutral out to a separate **X0** terminal.
- **Insulation:** the standard is a 220°C insulation system with a 150°C rise (40°C ambient + 150°C rise + 30°C hot spot). 115°C-rise and 80°C-rise units run cooler, at higher cost.
- **Temperature:** the top of the enclosure may run up to 50°C above the room. It is hot to the touch, and that is normal.
- **Overload:** about 200 percent of nameplate for 30 minutes, but no continuous overload capacity.
- **Nameplate** (NEC 2026 450.13(A)): manufacturer, kVA, frequency, voltages, impedance (25 kVA and up), required clearances for ventilated units, and insulation class.
- **Lifting points:** ventilated units lift from two holes in the core clamps after the top and front covers come off, or by forklift under the skid. The clamp edges are sharp, so pad the straps.

Part B — How It Works (the numbers that matter)

- **Turns ratio:** $V_{pri}/V_{sec} = N_{pri}/N_{sec}$. More primary turns than secondary turns means it steps the voltage down.
- **kVA rating** is apparent power. 3-phase current = $kVA \times 1000 \div (1.732 \times V_{line})$ (Module 1.0B).
- **% impedance (%Z)** does two jobs. It sets the voltage regulation (how much the secondary sags from no load to full load), and **it sets the available fault current on the secondary:**

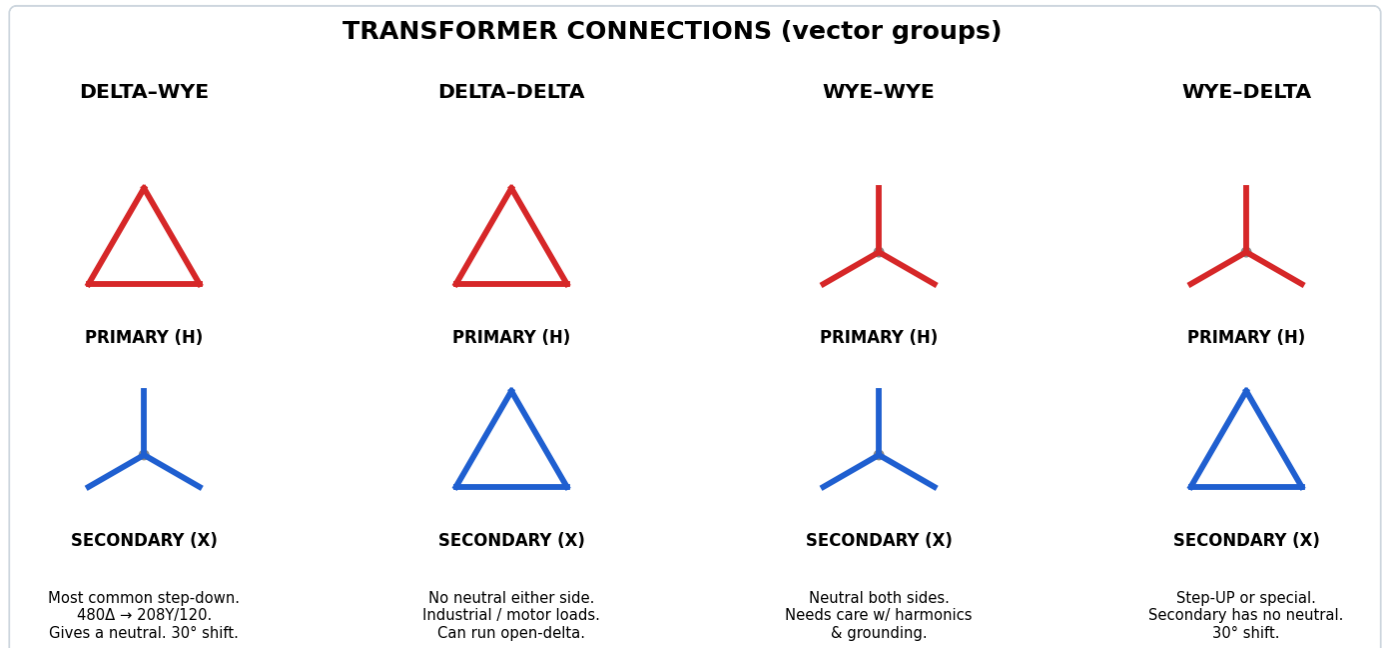
fault current $\approx$ secondary full-load amps $\div$ %Z. That number is what the downstream panel's interrupting rating must beat (NEC 110.9).

- **Inrush:** energizing a transformer draws a brief magnetizing inrush. Trade practice quotes 8 to 12 times rated current RMS for a few cycles. Eaton's glossary says the first peak "can be 30 to 40 times the rated current." The peak is what trips a breaker's instantaneous element.

Real nameplate data (Eaton, 480 V class, 150°C rise, aluminum)	45 kVA	75 kVA	112.5 kVA
No-load loss	125 W	193 W	256 W
Total loss at full load	1,220 W	1,761 W	2,306 W
Regulation at 100% PF	2.64%	2.26%	1.94%
Impedance (%Z)	3.51%	3.61%	4.37%
Sound level	45 dB	50 dB	50 dB
Primary current at 480 V	54.1 A	90.2 A	135.3 A
Secondary current at 208 V	124.9 A	208.2 A	312.3 A
Secondary fault current (unlimited supply)	about 3,560 A	5,770 A	7,150 A

- **Worked example 1, fault current.** 75 kVA at 3.61%: $208.2 \div 0.0361 = 5,770 \text{ A}$. A textbook 5%Z unit of the same size would give $208 \div 0.05 = 4,160 \text{ A}$. Lower impedance means more fault current, so always use the nameplate number, not a rule of thumb.
- **Worked example 2, regulation.** 2.26% on the 75 kVA means the secondary drops from about 208 V at no load to about 203 V at full load at unity power factor. Taps correct for a high or low supply; they don't fix regulation.
- **Paralleling two transformers** (Eaton): same phase shift and rotation, ratios within 0.5 percent, and impedances within 7.5 percent of each other on the same kVA base. Otherwise current circulates between them. Each one needs its own protection (450.9).
- **Ambient limits:** 40°C maximum and 30°C average over 24 hours. Derate above that, or above 1,000 m elevation.

Part C — Connection Types (Vector Groups)



The four connections. Delta-Wye is the everyday commercial step-down — it produces the neutral you need for 120V loads.

- **Delta-Wye** is the standard step-down (480Δ → 208Y/120). The wye secondary gives you a neutral and both voltages. It has a **30° phase shift** between primary and secondary, written in "clock" notation such as **Dyn1** or **Dyn11**.
- **Delta-Delta**: no neutral on either side. Industrial and motor loads. It can run "open delta" on two coils at 57.7 percent capacity.
- **Wye-Wye**: neutral on both sides, but needs careful grounding and harmonic handling.
- **Wye-Delta**: step-up or special uses. The delta secondary has no neutral.

What the delta primary does with harmonics. Hammond Power Solutions: 3rd and 9th harmonics "return along the neutral conductor and are trapped in the primary DELTA winding where they circulate causing significant extra heating. They do not flow through to the primary system, but they also are NOT cancelled." The delta keeps those harmonics off the feeder. It does not make them go away.

Step by step: hooking up a 480Δ to 208Y/120 transformer

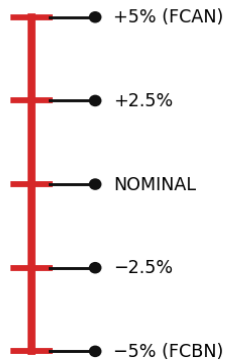
1. Read the nameplate wiring diagram. Lines land on H1-H2-H3. Tap leads (numbered 1 through 7 on many units) are on each coil.
2. Land the primary first, per the nameplate. Set the taps (Part D).
3. Energize the primary with the secondary open, measure the secondary, then de-energize.
4. Land the secondary: 208 V 3-phase from X1-X2-X3, 120 V from each X terminal to X0.
5. Check rotation with a phase-rotation meter before connecting any phase-sensitive load.

Never back-feed a transformer that isn't marked bi-directional, and never land anything on X0 or H0 of a wye winding on the supply side. Back-feeding raises inrush and causes nuisance trips, so it also needs time-delay protection.

Part D — Taps

PRIMARY TAPS — keep the secondary on target

primary (H) winding



Taps change the number of PRIMARY turns to hold the secondary voltage steady when the supply runs high or low.

• Supply LOW → move to a BELOW-normal (FCBN, -) tap → BOOSTS the secondary

• Supply HIGH → move to an ABOVE-normal (FCAN, +) tap → BUCKS the secondary

Set taps with the transformer DE-ENERGIZED, per the measured voltage and the nameplate. Re-measure after energizing.

Primary taps change the turns ratio to compensate for a high or low supply. Set them de-energized, per the measured voltage.

Standard taps are $\pm 2 \times 2.5\%$ on the primary, often written as two at $+2\frac{1}{2}\%$ FCAN (full capacity above normal) and four at $-2\frac{1}{2}\%$ FCBN (full capacity below normal). FCAN and FCBN mean the transformer still delivers full kVA on that tap. **Supply low → FCBN (-) tap → boosts** the secondary. **Supply high → FCAN (+) tap → bucks** it.

Step by step: picking and setting a tap

1. With the transformer de-energized and locked out, measure the actual supply line to line on all three phases at the line-side disconnect, under normal building load. Write it down.
 2. Read the tap table on the nameplate. A typical 480 V primary: 504 V = tap 1, 492 = 2, **480 = 3 (nominal)**, 468 = 4, 456 = 5, 444 = 6, 432 = 7.
 3. Pick the tap closest to what you measured.
 4. Move the jumpers the **same way on all three coils**. Schneider: "Move one tap at a time, or verify that the jumper lands per the wiring diagram ... Do not change taps while the transformer is energized ... Ensure taps are cleaned of varnish." Insulate unused tap leads and check them for tightness.
 5. Re-energize, measure the secondary line to line and line to neutral, compare to the nameplate, and record it.
- **Worked example 3.** You measure 466 V. The nearest tap is tap 4 (468 V, -2.5% FCBN). The secondary comes back to about 207 V instead of about 202 V on the nominal tap.

- **Worked example 4.** You measure 491 V. Use tap 2 (492 V, +2.5% FCAN).
- **Limits:** no more than 5 percent overvoltage at rated load, and no-load secondary no more than 110 percent of rated.

Part E — Grounding the Secondary (Separately Derived System)

A transformer secondary is a brand-new system with no ground reference until you give it one (NEC 2026 250.30). Skip it and line-to-ground faults won't clear and metal can float energized. Bond it twice and neutral current flows on the conduit and grounds.

Conductor	What NEC 2026 says	Size from
System bonding jumper (SBJ) 250.30(A)(1)	"An unspliced system bonding jumper ... shall be made at any single point on the separately derived system from the source to the first system disconnecting means or OCPD ... The system bonding jumper shall remain within the enclosure where it originates."	Table 250.102(C)(1), based on the secondary conductors
Supply-side bonding jumper (SSBJ) 250.30(A)(2)	Where the transformer and the first disconnect are in separate enclosures, "a supply-side bonding jumper shall be installed with the circuit conductors." A metal raceway can serve, but flex needs a wire	Table 250.102(C)(1)
Grounding electrode conductor (GEC) 250.30(A)(5)	Sized "for the derived ungrounded conductors" and "made at the same point on the separately derived system where the system bonding jumper is connected"	Table 250.66. To a ground rod it need not exceed 6 AWG copper; to a concrete-encased electrode, 4 AWG
Ground bar 450.12 (new in 2026)	A terminal bar for all grounding and bonding conductors, bonded to the enclosure, not over ventilation openings	—

Table 250.102(C)(1), copper secondary conductor	SBJ / SSBJ (copper)
2 AWG or smaller	8 AWG
1 or 1/0	6 AWG
2/0 or 3/0	4 AWG
over 3/0 through 350 kcmil	2 AWG
over 350 through 600 kcmil	1/0
over 600 through 1100 kcmil	2/0
over 1100 kcmil	12½% of the largest ungrounded conductor's area

Step by step: grounding the secondary

1. **Decide with your foreman where the SBJ goes:** at X0 in the transformer (usual when the panel is remote), or at the neutral bar of the first disconnect. Only one. If it's at the panel, run a full-size neutral and leave X0 unbonded.
2. **Mount the ground bar** on bare metal, paint scraped off, away from the vents. Schneider: "Remove paint from around the area where the ground terminal bar is mounted."
3. **Land the SBJ** from X0 to the bar, unspliced, sized from Table 250.102(C)(1).
4. **Land the GEC** at the same point, to building steel or the grounding electrode system, sized from Table 250.66. Never route it through vent or mounting openings (250.64(G)).
5. **Run the SSBJ** with the secondary conductors to the first disconnect. If the raceway is flex, it must be a wire.
6. **Land the primary feeder's equipment ground** on the same bar.
7. **Check with an ohmmeter:** X0 bonded to the enclosure, enclosure continuous to steel, and no neutral-to-ground continuity anywhere downstream of the SBJ.

Part F — Harmonics & the Modern Building

Computers, LED drivers, and VFDs are **nonlinear loads**. They draw current in pulses that create **harmonics**, and the **3rd harmonic adds up on the neutral**. Balanced switch-mode loads can put about $\sqrt{3}$ times the phase current on the neutral.

- **K-factor** = $\Sigma(I_h)^2 \times h^2$, adding up each harmonic's current squared times its number squared.
Worked example 5: 90% fundamental, 30% 3rd, 20% 5th: $(0.9^2 \times 1) + (0.3^2 \times 9) + (0.2^2 \times 25) = 0.81 + 0.81 + 1.00 = \mathbf{2.62}$, so specify a **K-4** unit. A purely linear load is K-1.
- **When K is unknown** (Acme): K-1 for resistance heat, incandescent lighting, motors; K-4 for welders, HID and fluorescent lighting, solid-state controls; K-13 for telecom, classrooms, and health-care branch circuits; K-20 for data-processing circuits and VFDs. "A Spectrum Analysis is the best source."
- **K-rated vs. harmonic-mitigating.** K-rated units survive the heat but "do very little to reduce the harmonic losses themselves." Harmonic-mitigating (zig-zag) transformers cancel the triplen flux in the secondary so those harmonics don't circulate in the primary. K-rated units ship with 200 percent neutrals.
- **Oversize the neutral** on circuits feeding many nonlinear single-phase loads. A harmonic neutral is a current-carrying conductor, so four in a raceway takes the 80 percent adjustment (310.15). Keep 208Y/120 feeders short, close to the load.

Part G — Protection (NEC 2026 450.5(B))

Method	Primary, 9 A or more	Primary, under 9 A	Primary, under 2 A	Secondary, 9 A or more	Secondary, under 9 A
Primary only	125%	167%	300%	not required	not required
Primary and secondary	250%	250%	250%	125%	167%

NEC 2026 Table 450.5(B) (Table 450.3(B) in 2023). Where 125 percent is not a standard size, "a higher rating that does not exceed the next higher standard rating shall be permitted." The 250 percent value is a ceiling with no round-up.

480Δ-208Y/120	Primary only	Primary + secondary: primary (250%)	Primary + secondary: secondary (125%)	Secondary copper at 75°C	SBJ / SSBJ
45 kVA	67.7 → 70 A	135 → 125 A	156 → 175 A	2/0 (175 A)	4 AWG
75 kVA	112.8 → 125 A	225.5 → 225 A	260 → 300 A	350 kcmil (310 A)	2 AWG
112.5 kVA	169 → 175 A	338 → 300 A	390 → 400 A	600 kcmil (420 A)	1/0

- **Why the 125% breaker trips on energizing.** Schneider recommends "the 250 % allowance in order to reduce the potential for nuisance tripping during energization. Secondary overcurrent protection will be required." The other fixes are an adjustable instantaneous set above the inrush, or time-delay fuses.
- **Secondary conductors** (240.21(C)): the round-up of 240.4(B) is not allowed for transformer secondary conductors, and a delta-wye secondary is not protected by the primary breaker. **Worked example 6, the 10-foot rule:** 75 kVA with a 225 A primary breaker: the secondary conductors must be at least $(225 \div 10) \times 480/208 = \mathbf{52\ A}$ where they leave the enclosure, and at least the load and the rating of the breaker they land on. **The 25-foot rule:** at least $(225 \div 3) \times 480/208 = \mathbf{173\ A}$, ending in a single breaker.
- **A panel fed through a transformer** must have its protection on the secondary side (408.36(B)). A 208Y/120 panel needs a main or a secondary breaker no larger than its bus.
- **Disconnect** (450.16): in sight of the transformer, or remote and lockable open, with the location field-marked on the transformer.

Part H — Install and Commission a Dry-Type Transformer

Receive, store, handle

1. Inspect for damage, check the packing list against the nameplate, and file any claim with the carrier right away.

2. Store indoors, dry, heated, packing on, vents covered. Outdoor units are not weatherproof until they are installed and energized.
3. After damp or uncontrolled storage, megger it before energizing. If it reads low, dry it (Schneider: two 120 V, 50 W lamps per coil under the coils). Never heat above 110°C.
4. Move it upright, on the pallet, with forks fully under the base. With a crane, use a spreader bar, cables at least 60 degrees from horizontal, hooks in the core-bracket holes, and padded straps. Use a lift, not a ladder, for wall and trapeze units.

Locate and mount

1. Confirm the nameplate matches the drawings.
2. Readily accessible to qualified persons (450.15). Away from the public, dust, moisture, and corrosives.
3. Vents "not blocked by walls or other obstructions," clearances as marked on the unit, and no storage on top (450.11). Typical rear clearance is 2 inches for 150 kVA and under and 6 inches or more for larger; the nameplate governs. Working space in front per 110.26.
4. Indoors, 112.5 kVA or less: 12 inches from combustibles unless there is a fire-resistant barrier (450.21(A)). Over 112.5 kVA: a 1-hour room, unless the unit has Class 155 or higher insulation and the separation or enclosure the exceptions allow (450.21(B)).
5. Mount through the four base holes on the floor, a wall bracket, or a trapeze, with anchors picked by the engineer of record. Check the bracket rating (Schneider wall kits are 700 to 850 lb, trapeze 1,200 lb). Don't set an open-bottom unit on a combustible floor.
6. Keep it away from corners, on a solid base. Then **loosen the four core-clamp nuts one full turn** so the core floats on its pads. Tighten all the enclosure panels. Remove shipping braces.

Raceway and terminations

1. Use flexible conduit at the enclosure to cut hum. Flex means a wire-type supply-side bonding jumper.
2. Enter only in the marked areas below the top terminal board. No top entry, because heat exhausts up the raceway.
3. Size conductors from the 75°C column even though the lugs are rated 90°C. Match lugs to copper or aluminum. Bundle each set's phases, neutral, and ground together inside the enclosure.
4. Clean contact surfaces. Use joint compound on aluminum or in harsh environments.
5. Primary first, then taps, then secondary and grounding.
6. Torque every lug and tap connection with a calibrated wrench to the marked value (NEC 2026 110.14(D)). If nothing is marked, Annex I gives hex-drive values: ¼ in. 200 lb-in, 5/16 in. 275, ⅜ in. 375, ½ in. 500.
7. Insulate spare tap leads. All panels on before energizing.

Pre-energize tests

Test	How	Accept
Visual	Nameplate, taps, clearances, torque, bonding of core, frame, enclosure, raceways	All correct
Contact resistance	Micro-ohmmeter across bolted joints	Investigate any joint more than 50% above the lowest similar joint
Insulation resistance	Winding to winding and winding to ground, 1,000 V DC, 1 minute; ground each winding at least 1 minute after	Schneider minimum 1 megohm. NETA ATS Table 100.5 for dry-type 0-600 V coils: 500 megohms
Turns ratio (TTR)	All taps, all phases	Within 0.5% between coils
Winding resistance	Only on units over 500 kVA	Within 5%
Ground point	Resistance from the ground lug to the enclosure, core, frame, clamps	Record a baseline

Vacuum the dust out first. If you use air, no more than 25 psi and dry air. No solvents.

Energize and load-check

1. PPE per NFPA 70E. Close the primary. Open it immediately at any visible or audible arcing. A rattle or loud hum means loose hardware.
2. Measure and record line to line, line to neutral, and line to ground on both windings. On a 208Y/120 with the SBJ in, expect about 208/120/120 and about 0 V neutral to ground.
3. If the voltage is off, de-energize and change taps.
4. Check phase rotation.
5. Under load, clamp all three phases and the neutral and compare to rated current. A neutral current close to the phase current points to triplen harmonics. Record loaded versus no-load voltage.
6. Field-mark the remote disconnect location (450.16) and the panel's fault-current label.
7. Turn over a record: insulation, TTR, contact resistance, voltages, neutral current, tap position, and the torque sheet. Test results are made available to the inspector (110.41(A)).

Safety. De-energize and lock out before any work inside, and let it cool; the coils and enclosure are hot. Schneider's DANGER block before every test: NFPA 70E PPE, qualified persons only, all power off, "Always use a properly rated voltage sensing device to confirm power is off," OSHA lockout, consider backfeed, tools out and covers on before re-energizing. Discharge the coils after an insulation test. Never change taps or connections energized. OSHA 1910.333(b): a qualified person tests to verify the circuit is de-energized, and parts that are not locked out are treated as energized.

Common mistakes

Mistake	Rule
Neutral bonded at X0 and at the panel	250.30(A), 250.6
No SBJ anywhere (floating system)	250.30(A)(1)
Missing or undersized wire SSBJ in flex	250.30(A)(2), Table 250.102(C)(1)
GEC not at the SBJ point, or sized from the primary feeder	250.30(A)(5), Table 250.66
Ground bar over paint or a vent	450.12
Nominal tap on a 466 V supply; taps moved energized	Nameplate tap table; manufacturer instructions
Rear vent against the wall, storage on top, set in a corner	450.11
Rigid conduit hard-piped; core-clamp nuts left tight	Manufacturer instructions (hum and vibration)
No secondary breaker ahead of a 208Y/120 panel	408.36(B), 240.21(C)(1)
Secondary conductors rounded up to the next breaker size	240.21(C)
Lugs not torqued, or wrong copper/aluminum match	110.14(D)
Energized after wet storage without a megger test	Manufacturer instructions

NEC 2026 Checkpoints (2023 number in parentheses where it moved)

- **450.5(B)** (450.3(B)) protection • **450.9** parallel units • **450.11** (450.9) ventilation • **450.12** (new) ground bar • **450.13** (450.11) nameplate.
- **450.14** wiring space • **450.15** (450.13) accessibility • **450.16** (450.14) disconnect • **450.21** indoor dry-type.
- **250.30** separately derived systems • Tables **250.66** and **250.102(C)(1)** • **240.21(C)** secondary conductors • **408.36(B)**.
- **110.9, 110.10** fault ratings • **110.14(D)** torque • **110.41(A)** test records.

Hands-On Field Exercise

- On a dry-type transformer, identify H1-H2-H3, X1-X2-X3-X0, the tap board, the core-clamp nuts, and the ground bar.
- From the nameplate kVA and %Z, calculate the secondary fault current and check it against the downstream panel's rating.
- Measure a supply, pick the tap from the nameplate table, and set it on all three coils de-energized.

- Wire a 480Δ to 208Y/120 hookup in the right order. Set the SBJ, GEC, and SSBJ and size each one from the tables.
- Size primary and secondary protection for a 75 kVA unit both ways, and work the 10-foot and 25-foot secondary conductor minimums.
- Megger and TTR a transformer and fill out a commissioning record.
- Calculate the K-factor for a measured harmonic spectrum and pick a K rating.

Sources used in this module (public documents)

- NFPA 70, National Electrical Code 2026 (free read-only access at [nfpa.org](https://www.nfpa.org)): Articles 110, 240, 250, 408, 450; Annex I.
- Schneider Electric Instruction Bulletin 43006-850-01, Dry-Type Transformers 1000 Volts and Below: [se.com](https://www.se.com)
- Eaton PUB53311, Dry-Type Distribution Transformers IOM; Eaton Consulting Application Guide Tab 19: [eaton.com](https://www.eaton.com)
- Hammond Power Solutions, Harmonic Mitigating Transformers FAQ: [hammondpowersolutions.com](https://www.hammondpowersolutions.com)
- Acme Electric (Hubbell), Harmonic Mitigating & Load Isolation Transformers catalog section.
- Mike Holt, "Grounding of Separately Derived Systems": [mikeholt.com](https://www.mikeholt.com)
- ANSI/NETA ATS Table 100.5. NFPA 70E, 2024 edition. OSHA 29 CFR 1910.333: [osha.gov](https://www.osha.gov)

Companion to Module 1.5. Next: Module 1.6 — Motors, Controls & MCCs.